ST3: Converting from the Lab Experiment to Flight Instrument

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Abstract – This paper describes Instrument Control Electronics (ICE) for the Space Technology Three mission. The mission is a dual-spacecraft formation-flying Michelson interferometer designed to perform the first long-baseline optical interferometry in space. ST3 is planned for launch in late 2005, and will demonstrate enabling technologies in the areas of separated spacecraft control systems, precise optical pathlength control, and interspacecraft laser metrology, all of which are critical to the performance of future planned NASA missions such as the Terrestrial Planet Finder.

The interferometer flight instrument is based on a laboratory instrument that been developed over the past ten years. The flight instrument is planning maximum use of the developed hardware and software.

There are many challenges in designing flight equivalent instrument electronics that's rugged, lower mass, lower power and reliable.

This paper describes the methods, approaches and processes that are being used to design instrument electronics that will meet the project requirements for cost, mass, power and performance.

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1. INTRODUCTION

The ST3 Mission involves the use of two spacecraft flying in formation with each other in an earth-trailing orbit. Ball Aerospace is designing the two spacecraft and JPL is designing the two instruments, one on each spacecraft.

In order to operate properly, the position of each spacecraft, in relationship to each other as well as the instrument pointing is critical. Figure 1 shows the Collector spacecraft (far spacecraft) in relation to the Combiner spacecraft (near spacecraft) as they point toward a common star.

Figure 1, ST3 Data Collection Configuration

The spacecraft will utilize flying formation sensors to control the positions to within centimeters. The instrument uses sensors and actuators to dynamically control sensor positions to nanometer resolution.

The subject of this paper is the portion of the instrument that will dynamically control the sensor position, based on 10 years of experience gained on ground based interferometers. This has been factored into the performance estimates for the instrument.

This paper will focus on the process that has been developed in order to take a lab-based experiment and converting the experiment to a flyable instrument.

2. INSTRUMENT DESIGN PROCESS

The typical sequence for developing flight equipment is a breadboard (non-qualification engineering model) followed by a Qualification (Qual) Engineering Model (EM) followed by a flight version.

The function of the breadboard is to demonstrate compliance with functional requirements and gain operation experiences. Often the software will be developed on the breadboard as well. The Qual-EM is used to qualify the design and the manufacturing process. The Flight unit incorporates the findings and the lessons learned during the developmental tests.

In the case of ST3, in order to make maximum use of the inherence of previous projects, the breadboard is actually a duplicate of previously developed ground based interferometers as shown in Figure 2 plus mission specific enhancements. For the purpose of this paper, we'll refer to this as the commercial prototype (CP).

From a flight perspective, the weakness of the process is the lack of consideration for product assurance requirements, i.e. electronic parts, reliability and environmental requirements. In order of priority, each CP was selected based on: a) functional requirements, b) availability and c) cost.

The typical flight approach is to redesign the electronics from ground up. Optimizing the mass, power and volume in order to meet flight requirements. However, for ST3, a dramatic change in the architecture would invalidate the inherited software, change the real-time performance, and postpone the delivery of breadboard.

After careful consideration, it was decided to retain the basic VME architecture of the instrument electronics and to convert each CP to a configuration that could be flight qualified.

In essence a copy of commercial prototype will stay in place allowing software development and testing with the optical bench to continue while individual CP design is evaluated and upgraded for flight.

Flight conversion priorities are as follows:

1. Meet flight requirements for environment, reliability and operability.
2. Operating System Compatible (VxWorks)
3. Minimum software impact (register level compatible)
4. Maintain the same system performance
5. Maintain I/O system compatibility
6. Reduce system power
7. Reduce system mass
8. Reduce system volume

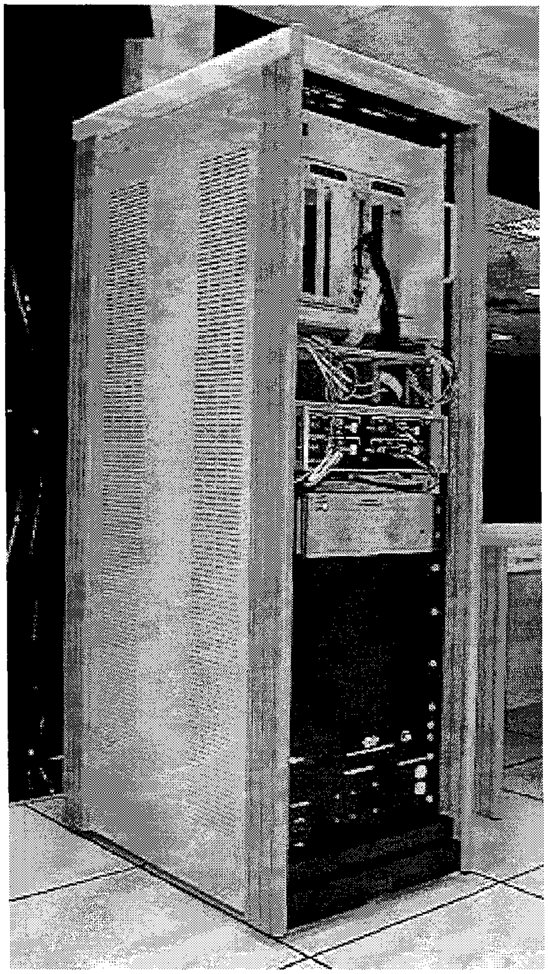

Figure 2, Commercial Prototype Equipment

Commercial Conversion process

The process depicted in figure 3 was developed to systemically replace CP to components that could be qualified to fly. The process starts by:

- Generating a list of functional(performance, I/O, mass, volume and power) and product assurance requirements based on ST3 mission and system requirements, followed by
- Use of figure 3 process to evaluate each CP (VME board) against the ST3 functional and product assurance requirements.

The process completes its cycle with documenting the tailored functional, and product assurance requirements in a design specification.

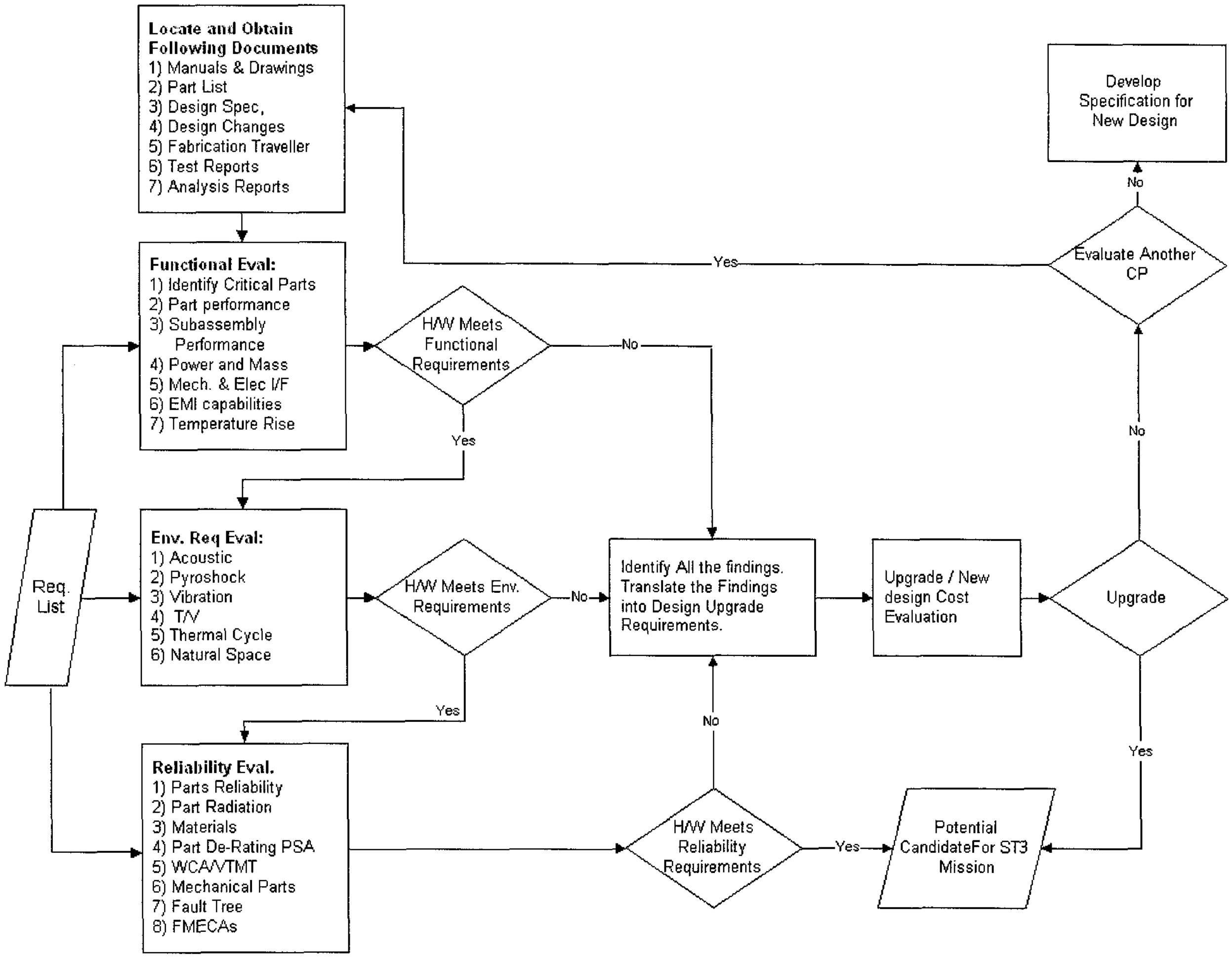

Figure 3, Commercial Product Flight Evaluation Process

Commercial Product Evaluation Process

The process depicted in figure 3 is similar to heritage hardware evaluation. The process ensures that the end product (after all the necessary upgrades) meets the performance, interface, mass, power and product assurance requirements of ST3. The process begins with obtaining the entire design and development documents followed by functional, environmental and reliability evaluations.

The first gate in the process is functional evaluation. The process focuses on the functions that are required for ST3 mission followed by I/F, mass, power and volume requirements.

The environmental requirement evaluation focuses on comparing ST3 environmental requirements with the available test data. The evaluation will identify areas requiring design upgrade and additional testing.

The reliability evaluation process focuses on the adequacy of the design margin, reliability of electronic parts.

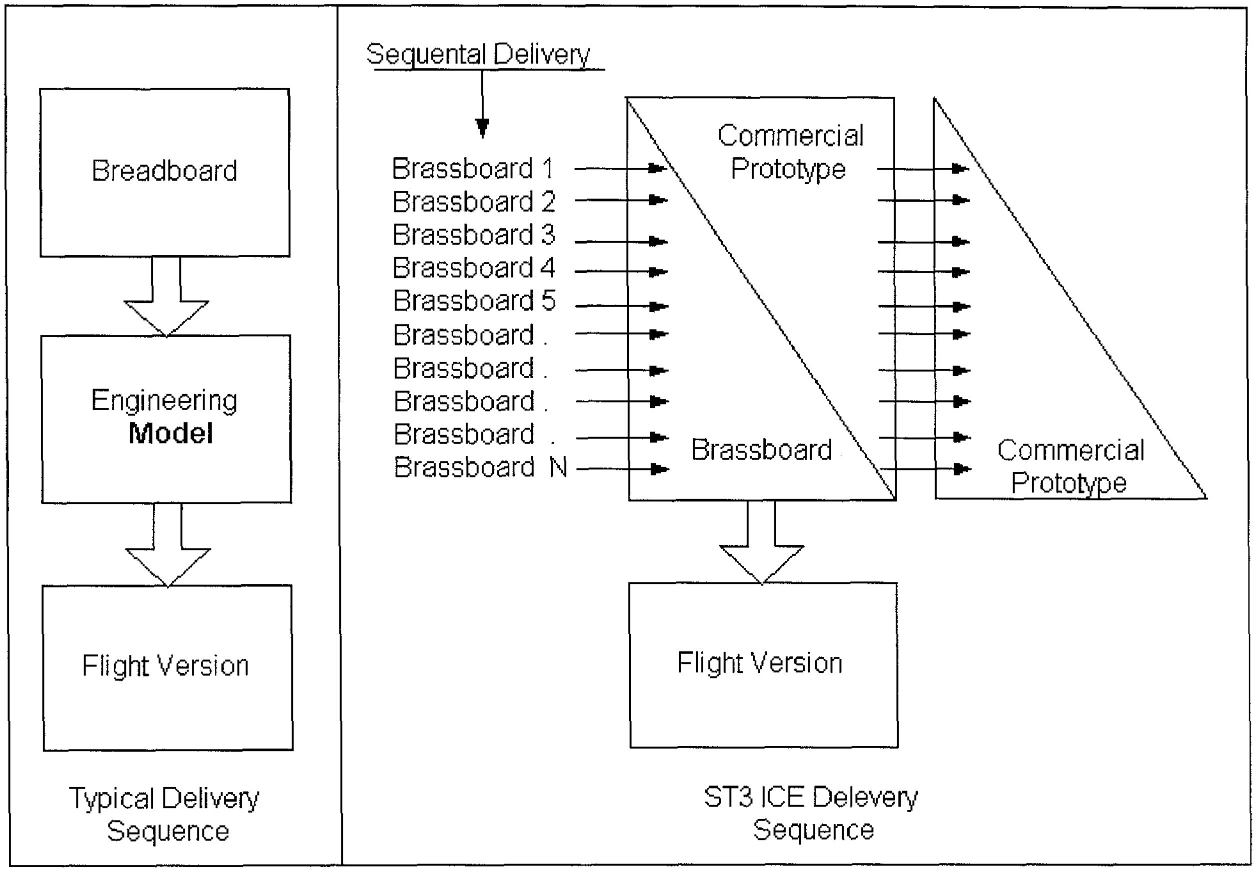

Figure 4, Comparison between the Typical Sequence and the ST3 Sequence

Sequential Delivery Process

The delivery of the brassboards occurs sequentially, over the period of many months. Because each brassboard unit is compatible with the board that it is replacing, major system level debugging will not be necessary.

Figure 4 compares the typical JPL delivery sequence to the ST3 ICE Delivery sequence. The typical sequence prevents any system testing to take place until the mission specific breadboard is designed and delivered.

The ST3 sequence takes advantage of existing commercial equipment to allow instrument level development to occur even before flight requirements is defined or design staff hired.

The order of the commercial to brassboard development is determined by the level of maturity of different portions of the instrument design. A diagram of the commercial prototype is shown in Figure 6. As you will note, there are 9 VME boards in the commercial prototype. As the Flight design progresses, the order of the board conversion process can be determined.

The flight unit will include functions that are not required in the commercial prototype. Examples are; Mil-Std-1553 Spacecraft interface and engineering telemetry collection. These functions will be sequenced to mesh with the delivery of the converted functions.

At the completion of the brassboard delivery sequence, the project will have two units at it's disposal, the original commercial prototype as well as the newly delivered brassboard version.

If software development requires development stations, then the cost for duplicating the commercial units will be much more preferable to the costs for duplicating the brassboard version.

Testbed / Flight Configuration Comparison

The similarity between the commercial prototype and the flight configuration can be seen in Figure 5and Figure 6.

Additional Flight Components

Just as the flight instrument does not need all the features of the commercial prototype, there are some features needed by the flight unit, not required by the commercial prototype.

These new flight features will be able to be added as necessary into the testbed. It is planned that the new features can be developed and inserted into the testbed without invalidating the instrument software or hardware performance.

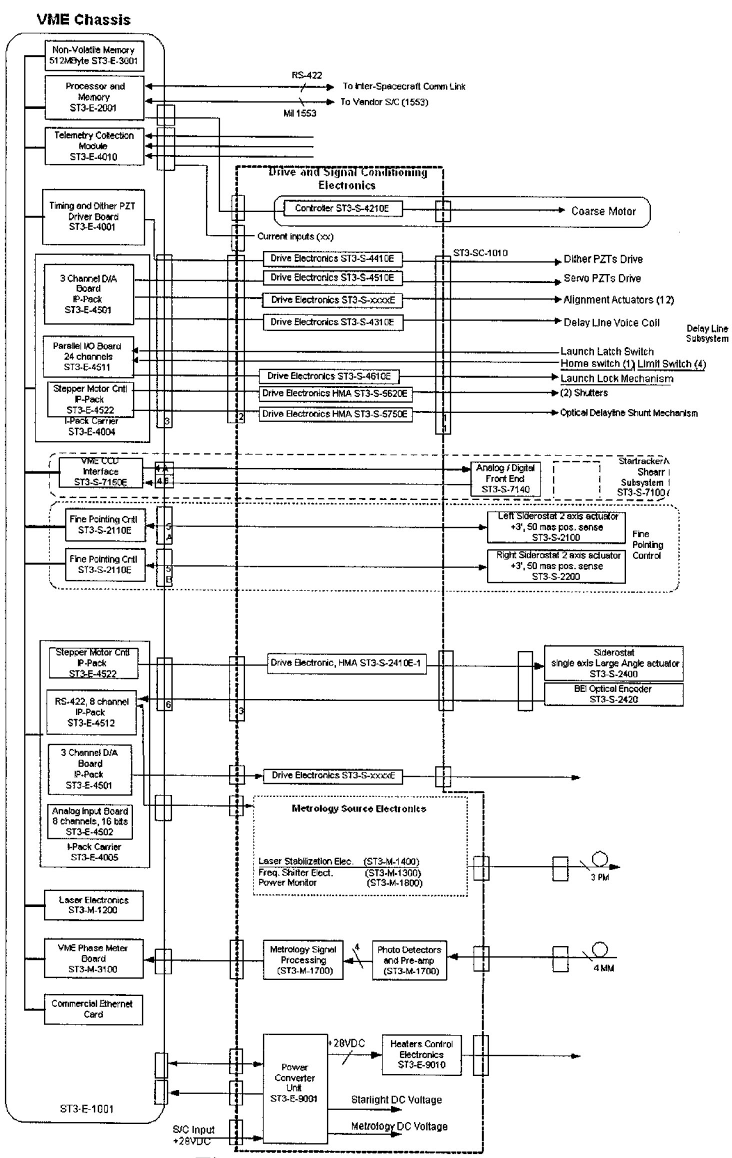

Figure 5, Flight Configuration

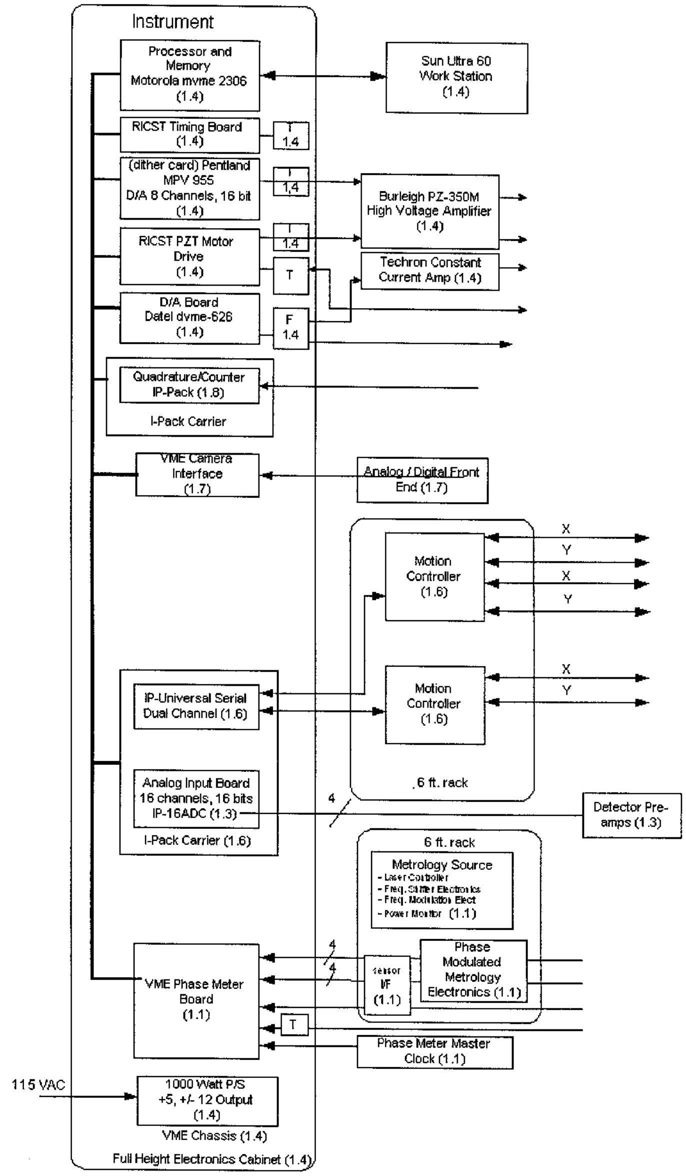

Figure 6, Commercial Prototype Configuration

The following is a summary of flight capabilities that must be added to support the flight requirements.

1. The flight configuration utilizes and additional non-volatile memory board to support flight program boot from local memory vs. booting from an Ethernet connection.
2. The flight configuration also requires the ability to measure instrument voltage, currents and temperatures. An engineering measurement board will be added to the flight configuration to support the flight requirements
3. The flight configuration also requires the ability to control power distribution.
4. The flight configuration needs to control the heaters on the optical bench.

3. EARLY RESULTS

The first board to be converted from a commercial prototype to a brassboard configuration is the Timing Board. The commercial prototype is shown in Figure 7. The board was developed by the RICTS project for ground based interferometers. The board is used as the timing synchronizer for the instrument. It provides timing interrupts to the processor and clock signals to the metrology and starlight subsystems of the instrument.

As per our process, the requirements of the board in the flight configuration were reviewed. We worked closely with the original RICTS design engineers to determine which features that the commercial prototype had, but were not needed for the ST3 mission. Features not required were removed or deleted. For example, the commercial prototype supported eight (8) VME interrupts. It was determined that the brassboard need to support only three (3) interrupts. Also, the commercial prototype supported 32 channels of programmable digital outputs. The brassboard was reduced to eight (8) channels.

Also as per our process, the parts on the board were evaluated for flight applicability. It was determined that the Altera FPGA should be replaced with Xilinx FPGA

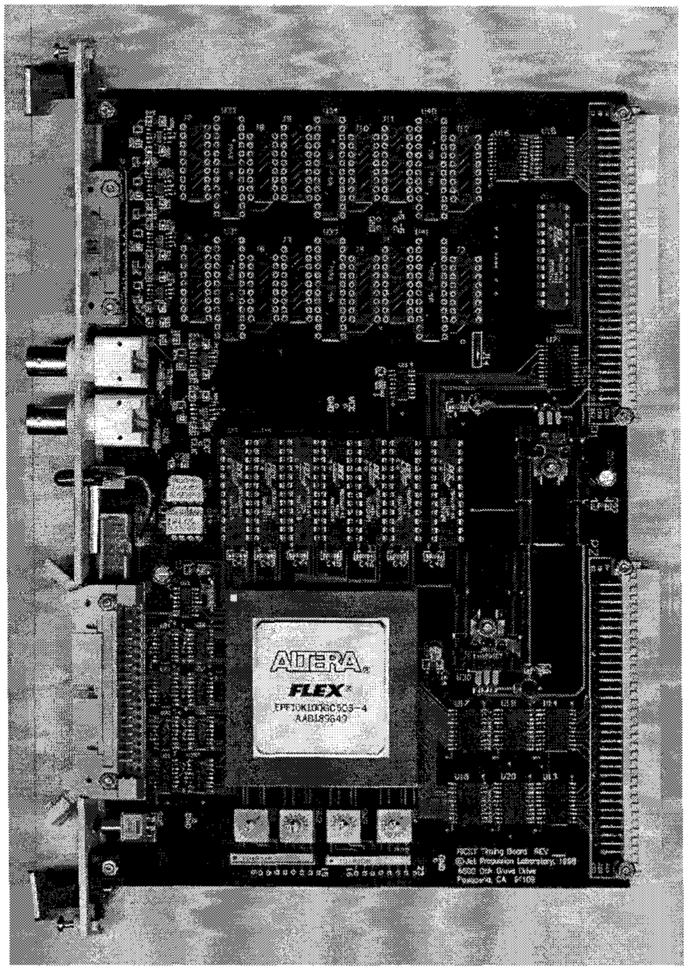

Figure 7, Timing Board, Commercial Prototype

because the Xilinx part is available in a rad tolerant version. The VME interface chips (VME 2000 and VME 3000) manufactured by PLX Technology were not available in a rad tolerant version. The function of the parts were "cloned" and implemented in the UTMC's 22V10 rad hard PALs. The onboard voltage regulators were replaced and the VME backplane was modified to supply the 3.3 volts necessary for the FPGA. Switches were replaced with null resistors (jumpers) and connectors that were not available in flight configurations were either changed or deleted.

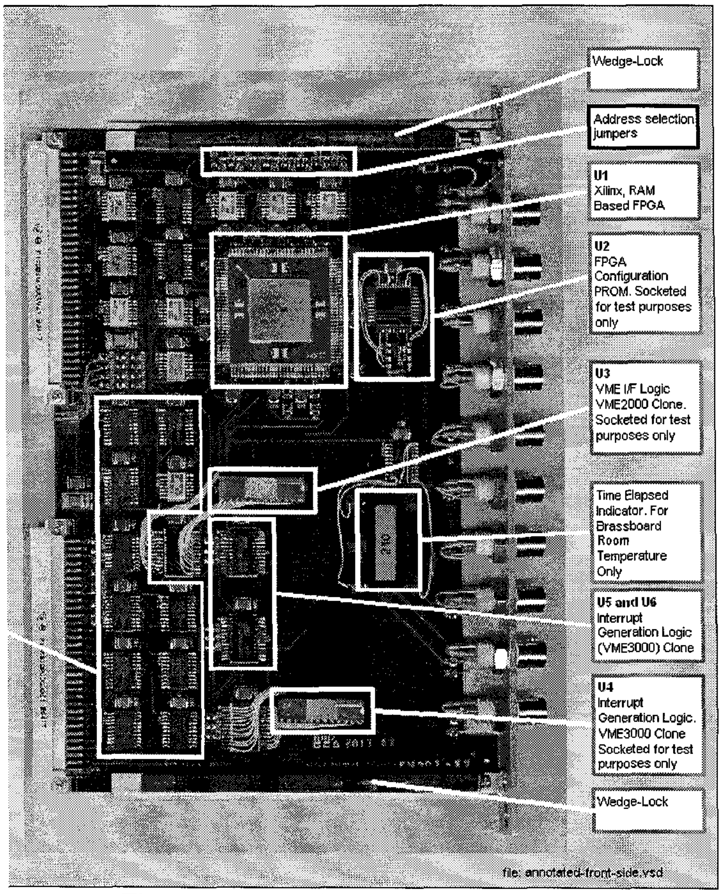

Figure 8, Timing board, Brassboard Version

The resulting brassboard is shown in Figure 8. As you will note, all parts are in flight-like packaging (quad and DIP flat packs). Parts that are "hay-wired" to sockets are only socketed for test purposes.

After assembly, the board was thoroughly debugged on a lab bench using Windows based VME system and TCL scripting language for board level diagnostics.

The final step was to insert it into the commercial prototype were it performed as expected.

4. SUMMARY

The ST3 Project has developed a set of procedures to insure that the flight instrument will make maximum reuse of the experiences learned for ground based interferometers.

We expect that by upgrading from ground based designs the flight instrument development schedule will be reduced and the performance risk associated with unproved system design will be reduced.

The upgrading is a methodically performed and can be summed in the chart shown in Figure 9.

When the tasks are broken down and handled as separate tasks that can be handled by different people, then the conversion process can be handled in a parallel fashion and not necessarily serially.

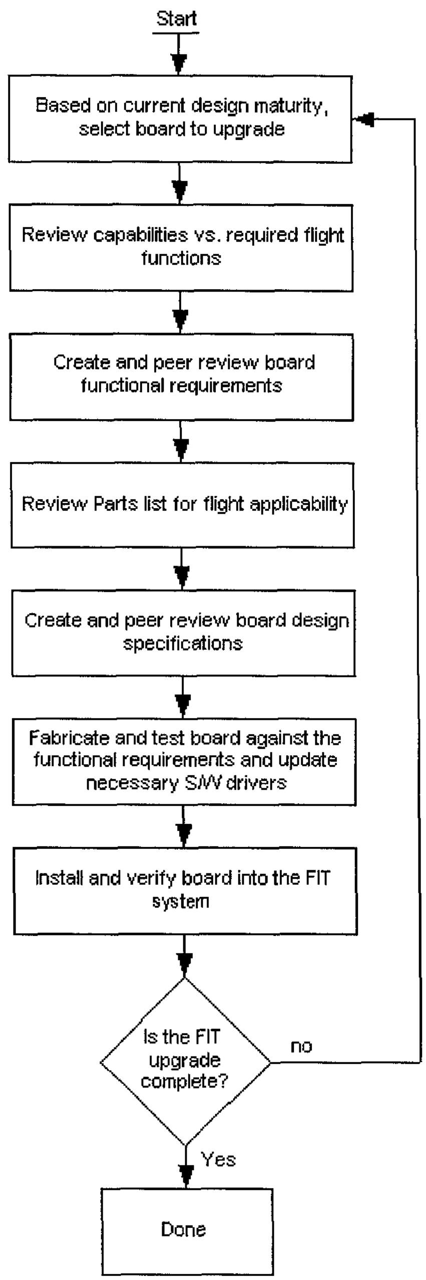

Figure 9, Conversion Process

5. CONCLUSION

This paper has described the detailed process that ST3 will be using for migrating from commercial level equipment to a design that can be flight qualified. The process will not impact ongoing development work as new elements are added. Large portions of the inherited interferometer software will not be affected by the additions.

The risks in terms of unknown performance constraints will not be an issue because of the incremental delivery approach.

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